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(21) International Application Number: PCT/US95/06204 (22) International Filing Date: 19 May 1995 (19.05.95) (30) Priority Data: 08/245,957 19 May 1994 (19.05.94) US (71) Applicant: EXOS, INC. [US/US]; 2A Gill Street, Woburn, MA 01801 (US). (72) Inventors: MARCUS, Beth, A.; 78 Woburn Street, Lexington, MA 02173 (US). OSBORNE, Timothy; 10 Udine Street, Arlington, MA 02174 (US). AN, Bin; Apartment 2, 21 Newport Street, Arlington, MA 02174 (US). EBERMAN, Brian; 264 Willow Avenue, Somerville, MA 02144 (US). (74) Agent: PASTERNAK, Sam; Choate, Hall & Stewart, Exchange Place, 53 State Street, Boston, MA 02109 (US).		(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG). Published <i>With international search report.</i>
(54) Title: INTERACTIVE SIMULATION SYSTEM INCLUDING FORCE FEEDBACK INPUT DEVICE		
(57) Abstract <p>Interactive simulation including force feedback. The system includes a computer game display unit programmed with simulation rules. A control unit is connected to the computer and provides information and control signals to the computer to interact with the stored simulation rules and to receive information and control signals from the computer. A movable structure for movement in at least two degrees-of-freedom by an operator is interconnected to the control unit by means of actuators. A programmable unit processes signals and information from the computer to generate signals to drive the actuators so as to apply forces in the at least two degrees-of-freedom to the movable structure and thereby to the operator. The applied forces are based on internal programming within the programmable unit, events occurring in the simulation and movements of and forces applied to the movable structure by the operator. The system of the invention thereby provides continuous interaction among motion of and forces applied by the movable structure, the events in the simulation and forces applied to and applied by the movable structure.</p>		

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INTERACTIVE SIMULATION SYSTEM INCLUDING FORCE FEEDBACK INPUT DEVICE

Background of the Invention

This invention relates to interactive simulations, and more particularly to simulations and games including force or touch feedback to a joystick or multi-axis controller or input device.

Interactive computer simulations and interactive video games often include a movable structure generally known as a joystick to provide inputs for the simulation or game. Oftentimes, the joystick is strictly an input device by which signals are conveyed to the processing unit of the computer. These joysticks do not provide any tactile or force feedback to the user.

The Atari Hard Drivin[®] video game provides one-dimensional force feedback to a steering wheel or a brake pedal. That is, during a game, torques are generated on the steering wheel which simulate those torques which would be experienced during, for example, cornering in a car. See also, U.S. Patent No. 5,044,956. In a more general simulation context, control elements including force feedback are known in elaborate flight simulators costing many millions of dollars. Heretofore, there has been no multiple-degree-of-freedom joystick suitable for games and simulations and suitable for arcade and home use.

Summary of the Invention

The interactive simulation system of the invention includes a computer or game display unit programmed with simulation rules. A control unit is connected to the computer and provides information and control signals to the computer to interact with the stored simulation rules and to receive information and control signals from the computer. A movable structure for movement in at least two degrees-of-freedom by an operator is interconnected to the control unit by means of actuators. A programmable unit processes signals and information from the computer to generate signals to drive the actuators so as to apply forces in the at least

two degrees-of-freedom to the movable structure and thereby to the operator. The applied forces are based on internal programming within the programmable unit, events occurring in the simulation and movements of and forces applied to the movable structure by the operator. The system
5 thereby provides continuous interaction among motion of and forces applied by the movable structure, the events in the simulation and forces applied to and applied by the movable structure.

In a preferred embodiment the simulation system is an interactive video game and the programmable unit resides in the control unit. In this
10 embodiment, the movable structure is a joystick with two degrees-of-freedom. The actuators include electric motors driving a low-friction, low-backlash transmission. The programmable unit includes integrated electronics for controlling feedback and modeling user interaction with the simulation or game. It is also preferred that information compression
15 technology be used so that much smaller information sets can be processed and communicated while still achieving a desired experience.

By providing touch or force feedback, the system of the invention more effectively involves the operator in the simulation or game. For example, in two-dimensional games such as flight simulators the present
20 touch feedback is used to allow the player to feel the difference in performance between a small general aviation airplane and a high performance military fighter and to feel environmental forces such as air turbulence or updrafts. In this case the joystick, known as a PowerStick™, will feel a variety of programmable effects including feeling "stiffer" or
25 "softer" depending on which type of airplane is being "flown" by the simulation user. In three-dimensional games (which are just now becoming available) force feedback is particularly valuable because navigating in a three-dimensional environment is often difficult and the touch feedback provided by the invention will enable the user to feel objects which are
30 being encountered and provide a real-time indication of where an object

controlled by the user or player is. In games involving contact, such as fighting games, the invention simulates and displays to the operator's hand the feel of collisions with objects encountered during the game or simulation and interaction with terrains of different textures.

5

Brief Description of the Drawing

Fig. 1 is a block diagram illustrating the overall system of the invention.

10 Fig. 2 is a plan view, with parts broken away, of the force feedback control unit of the invention.

Figs. 3 and 4 are side and front cross-sectional views, respectively, of the joystick control unit of the invention.

15 Fig. 5 is a cross-sectional view of an alternative embodiment of the invention.

Fig. 6 is a bottom view of the embodiment of Fig. 5.

Fig. 7 is a detail taken from Fig. 5.

Fig. 8 is a detail taken from Fig. 6.

20 Fig. 9 is a block diagram of the signal and communication paths in the operation of the invention.

Figs. 10 and 11 are perspective illustrations of a character in an interactive game with force feedback according to the invention.

Description of the Preferred Embodiment

25 The overall system of the invention is illustrated schematically in Fig. 1. A control unit 10 includes a movable structure such as a joystick 12. The control unit 10 also includes a programmable section 14. It will be appreciated that the unit 14 need not be a part of the control unit 10; it could be separate or part of the computer 16. A general purpose digital computer
30 16 such as a personal computer or game display unit is programmed with

simulation or game rules. The output from the computer 16 is displayed on a video monitor 18. The control unit 10 is connected to the computer 16 and provides information and control signals to the computer 16 to interact with the stored simulation rules and to receive information and control
5 signals from the computer 16. The programmable unit 14 processes signals and information from the computer 16 and generates inputs to, and processes outputs from the joystick 12.

With reference now to Fig. 2, the control unit 10 supports the movable structure or joystick 12 for two degrees-of-freedom motion with
10 respect to the control unit 10. The joystick 12 also includes at least one button type switch 20 for sending signals to the computer 16.

With reference now to Figs. 3 and 4, the control unit 10 is shown without its cover. The control unit 10 includes electric motors 30 and 32 along with angular rotation sensors 34 and 36. The motors 30 and 32
15 include shafts bearing capstans 38 and 40. The sensor 34 responds to the angular orientation of capstan 38 and the sensor 36 responds to the angular orientation of the capstan 40 to generate signals for use by the programmable unit 14. A cable transmission mechanism driven by the capstan 38 is adapted to rotate the joystick 12 about an axis 42, that is, left
20 and right in Fig. 3. Similarly, the capstan 40 is adapted to rotate the joystick 12 about an axis 44 so that it moves into and out of the plane of Fig. 3. As shown in Fig. 4, a drum 46 cooperates with the capstan 38 to effect rotation. This transmission system has low backlash and low friction. The sensors 34 and 36 provide an output proportional to angular orientation
25 of the respective motor 30 and 32 shafts.

As shown in Fig. 1, the control unit 10 is connected to the computer 16 so that information and control signals can pass in either direction between the control unit 10 and the computer 16. The programmable unit 14 may be included in the control unit 10 housing or may be part of the
30 computer 16 itself. The programmable unit 14 processes signals from the

computer 16 using internally stored rules and equations to generate signals to drive the motors 30 and 32 so as to produce forces with two degrees of freedom to the joystick 12 and to a user (not shown) operating the joystick 12. The applied forces are based on internal programming within the programmable unit 14, events occurring in the simulation and movements of and forces applied to the joystick 12 by an operator (not shown). The system therefore provides continuous interaction among motion of the joystick 12, events in the simulation and the forces applied to and applied by the joystick 12.

10 With reference now to Figs. 5, 6, 7 and 8, another embodiment of the control unit 10 is described. A motor 50 through a linkage denoted generally at 52 rotates a shaft 54. The shaft 54 passes through an angular orientation sensor such as potentiometer or encoder 56. The shaft 54 causes a bracket 58 to move left and right in Fig. 6 and engages a lower portion 59 of the joystick 12 to cause the joystick 12 to move left and right in Fig. 5. The slotted bracket 58 is supported in bearings 60 and 61.

15 Similarly, a motor 62 drives a linkage 64 which rotates a shaft 68 which passes through a potentiometer or encoder 70. The shaft 68 causes a bracket 72 to rotate as shown in Fig. 6 to cause the joystick 12 to move into and out of the plane of Fig. 5. The bracket 72 is supported by bearings 73 and 74.

20 As will be appreciated, as the motors 50 and 62 are energized, the joystick 12 is driven with two degrees-of-freedom, that is, left and right and in and out of the plane of Fig. 5. The rotational sensors 56 and 70 provide electrical outputs proportional to the angular orientation of their respective shafts. With reference to Fig. 5, the programmable unit 14 is shown as a circuit board 76 which may include the motor control and signal processing electronics.

25 With reference now to Fig. 9 the programmable unit 14 includes a microcontroller 80 which communicates with the computer 16 (Fig. 1)

through a host connection 82. The microcontroller 80 is any suitable processor such as a digital signal processor (DSP) or RISC architecture processor for enhanced operation. Further, the system can be designed for an upgradable processor core, independent of I/O hardware. In addition, the possibility exists of changing the controller's executable code from the host computer. This flexibility opens up the opportunity to customize the operation of the device for specific host applications. The microcontroller 80 executes boot code upon start up that loads in default operating firmware from on-board non-volatile memory (or removable media, e.g., memory cards) and waits for a host command to begin execution, or to download operational software. The default operation code provides general force feedback, positional, and other functions. Code downloaded to the microcontroller 80 from the host computer 16 can be tuned for specific functions and/or characteristics. The downloaded code can either be native executable binary or pseudocode for an on-board interpreter. An interpreter implementation removes the need for the host to know what processor resides on the control unit. Amplifiers 84 and 86 drive the motors 30 and 32 in the embodiment of Fig. 3 or the motors 50 and 62 in the embodiment of Fig. 6. It is to be noted that currents in the drive motors can be used to determine torque which can also be inferred from strain gauges or other types of force/torque sensors (not shown) on drive cables or shafts. It should also be noted that the torque transmission can be a four-bar linkage as illustrated in Figs. 5 and 6, a cable transmission illustrated in Figs. 3 or 4 or a belt or gear train. If desired for a particular application, a speed reduction can be built into the transmission to amplify the torque applied to the joystick 12. In applications where space and motor size are not constrained, the motors 50 and 62 can be directly mounted onto shafts 54 and 68 in Fig. 6 without transmissions.

An example of a game or simulation illustrating the technology of the

invention disclosed herein will now be described in conjunction with Figs. 10 and 11. The system of the invention has been integrated into an IBM Windows demonstration game which itself does not form a part of this invention. In this exemplary game, a character 90 fights his way through a series of different terrains to reach a treasure (not shown). The walking, running, jumping, squatting, punching and kicking of the character 90 are controlled by movements of the joystick 12. When, for example, the character 90 hits a patch of ice, the force being felt by the player goes to zero and can in fact use the motion and forces applied by the operator to further exaggerate the effect by actively getting out of the way of the operator to simulate sliding. On rough terrain, vibrations and pulses are felt by the game player in proportion to the objects encountered. If the character 90 is jumping and hits a tree or other object, the player will feel the stiffness of the object through forces transmitted through the joystick 12. When the button 20 is depressed, the character 90 stops moving and kicks or punches as shown in Fig. 11. Depending on the nature of the object being punched or kicked, and also depending on other events in the game, the forces experienced by the player will be different. Also, the velocity of the motions change the forces felt as they would in real fighting. Real physical models of the environment and objects encountered are programmed into the programmable unit 14 so that feedback is virtually instantaneous and independent of the graphics update of the computer 16. This architecture also makes the game fully interactive in which game outcomes unanticipated by the programmers occur based on the performance of the player. Because of the force feedback, the player is more actively involved in the game since the forces applied to the joystick 12 realistically simulate forces which would be felt by the character 50 in the game.

What is claimed is:

Claims

1. Interactive simulation system comprising:
 - a computer programmed with simulation rules;
 - a control unit connected to the computer and adapted to provide information and control signals to the computer to interact with the stored simulation rules and to receive information and control signals from the computer;
 - a moveable structure adapted to be moved with at least two degrees-of-freedom by an operator and interconnected to the control unit through actuators; and
 - programmable means for processing signals from the computer to generate signals to drive the actuators to apply force and touch feedback in the at least two degrees-of-freedom to the moveable structure and to the operator, the applied forces based on internal programming within the programmable means, events occurring in the simulation and movements of and forces applied to the moveable structure by the operator, whereby there is continuous interaction among motion of the moveable structure, the events in the simulation and forces applied to and applied by the moveable structure.
2. The interactive simulation system of claim 1 wherein the programmable means is included with the control unit.
3. The interactive simulation system wherein the actuators comprise:
 - at least two motors for generating forces about respective axes of rotation.

4. The interactive simulation system of claim 1 wherein the actuators include at least one cable drive.

5. The interactive simulation system of claim 1 wherein the actuators include a four-bar linkage.

6. The interactive simulation system of claim 1 wherein the actuators include electrical motors and each motor includes means for determining angular orientation of the motor shaft.

7. The interactive simulation system of claim 1 wherein the programmable means is located apart from the control unit.

8. The interactive simulation system comprising:
a computer programmed with simulation rules;
a control unit connected to the computer and adapted to provide information and control signals to the computer to interact with the stored simulation rules and to receive information and control signals from the computer;
a movable structure adapted to be gripped and moved by an operator in two degrees-of-freedom and interconnected to the control unit by means of electric motors and a transmission; and

programmable means associated with the control unit for processing signals from the computer to generate signals to drive the motors to apply forces in the two degrees-of-freedom to the movable structure and to the operator, the applied forces based on internal programming within the programmable means, events occurring in the simulation and movements of and forces applied to the movable structure by the operator, whereby there is continuous interaction among motion of the movable structure, the events in the simulation and forces applied to and applied by the movable structure.

9. Control unit for interacting with a computer, comprising:
- a movable structure adapted to be moved with at least two degrees-of-freedom by an operator;
 - actuators adapted to apply force and touch feedback to the movable structure with at least two degrees-of-freedom; and
 - programmable circuitry for processing information to generate signals to drive the actuators to apply force and touch feedback in the at least two degrees-of-freedom to the movable structure and to an operator.

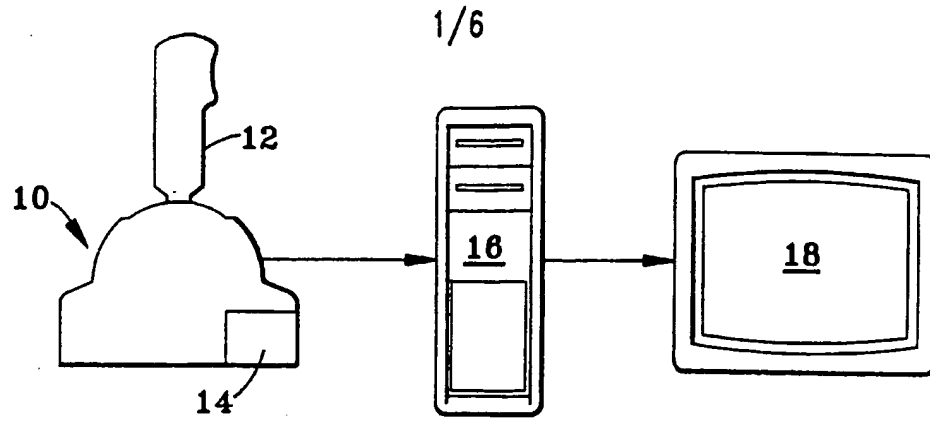


FIG. 1

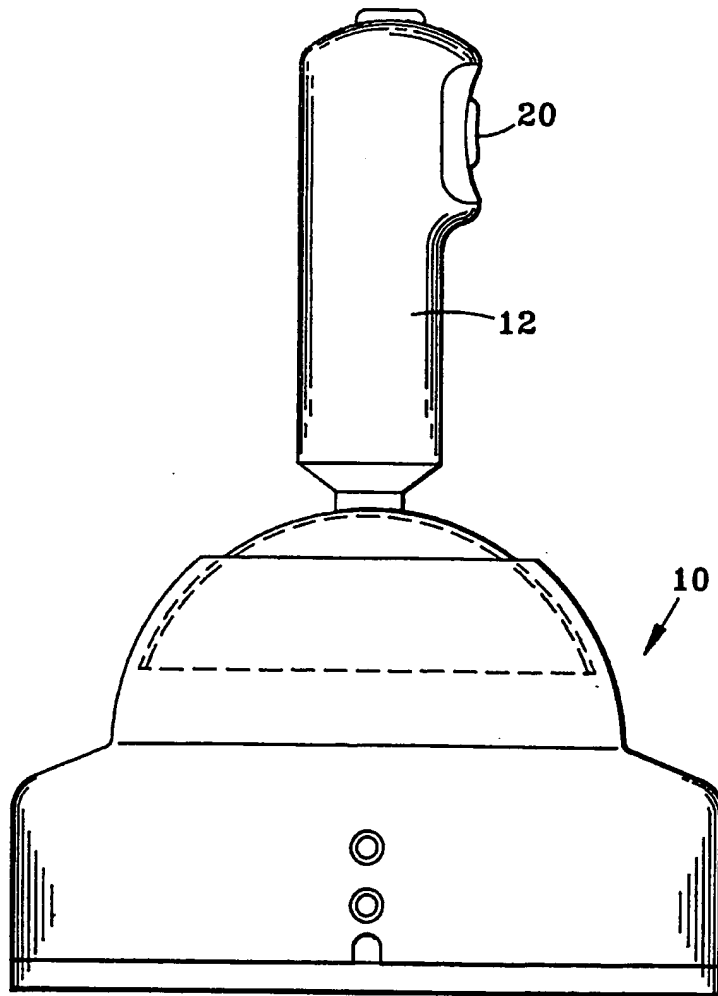


FIG. 2

2/6

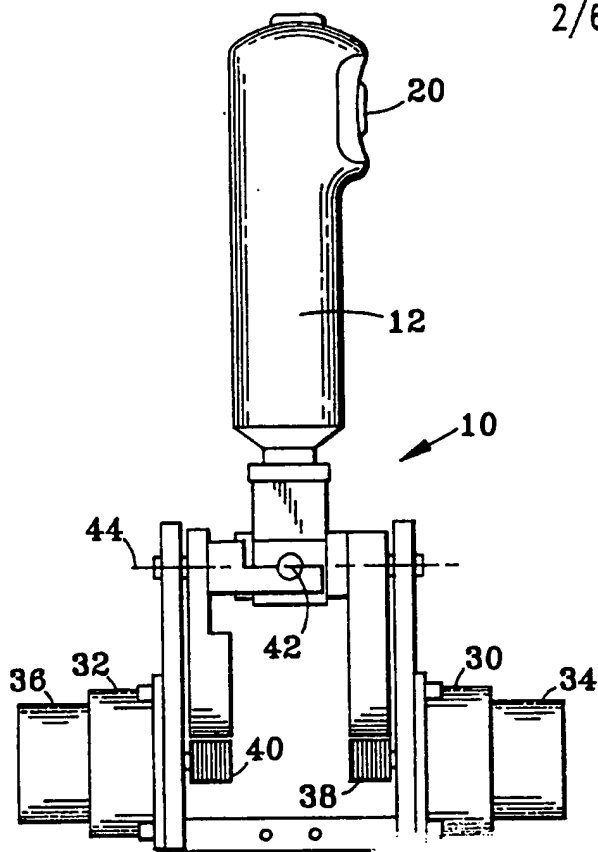


FIG. 3

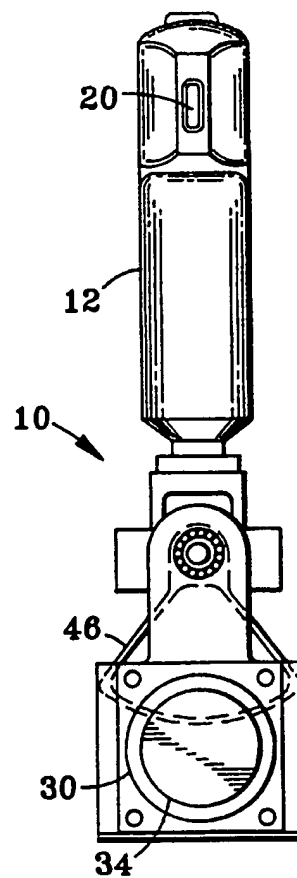


FIG. 4

3 / 6

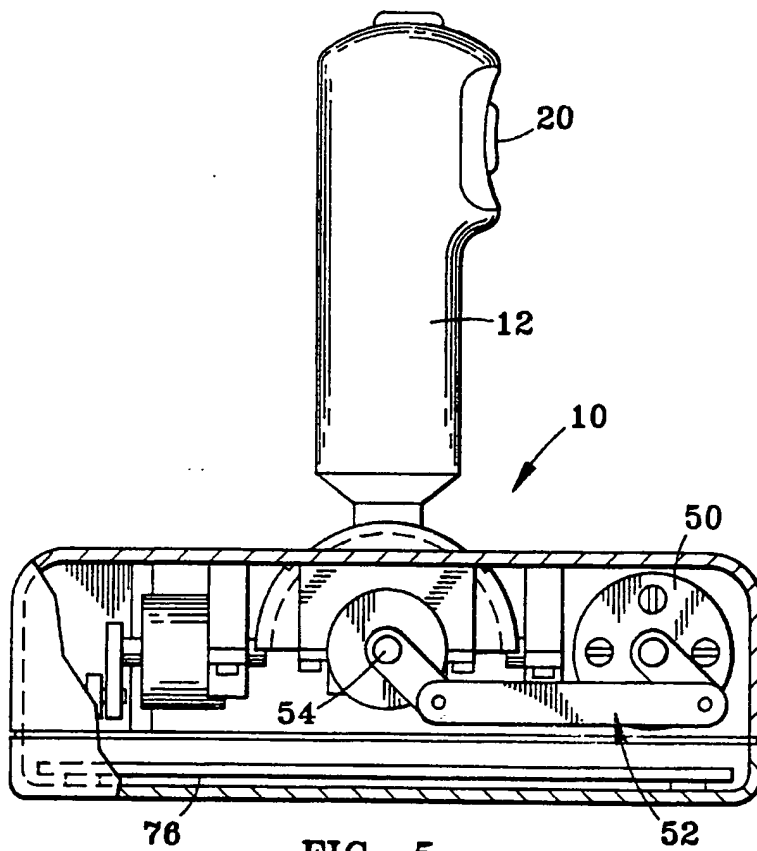


FIG. 5

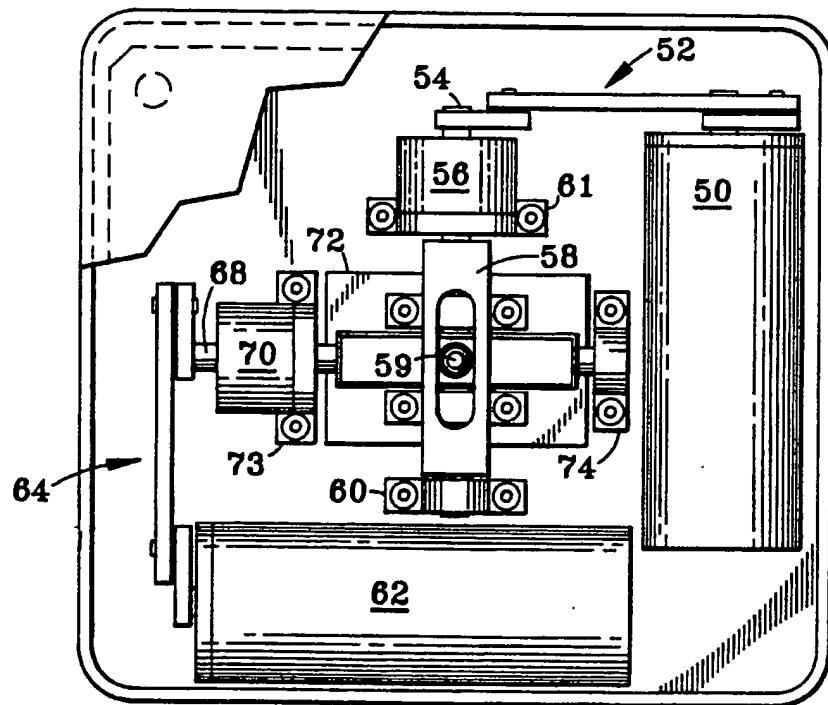


FIG. 6

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4/6

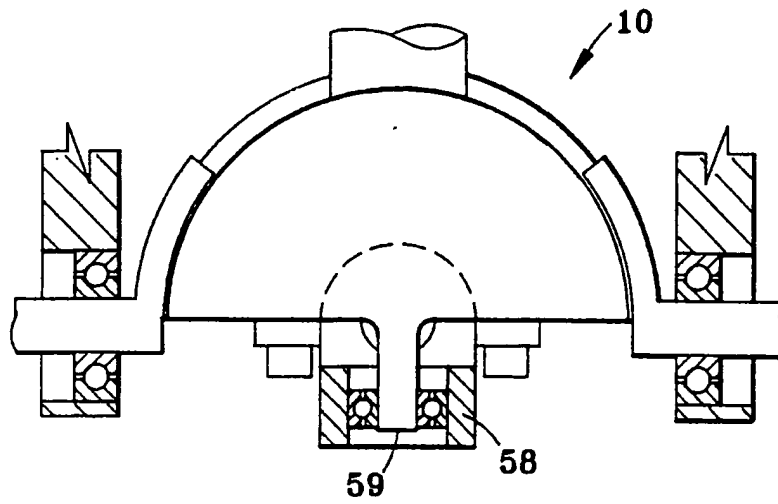


FIG. 7

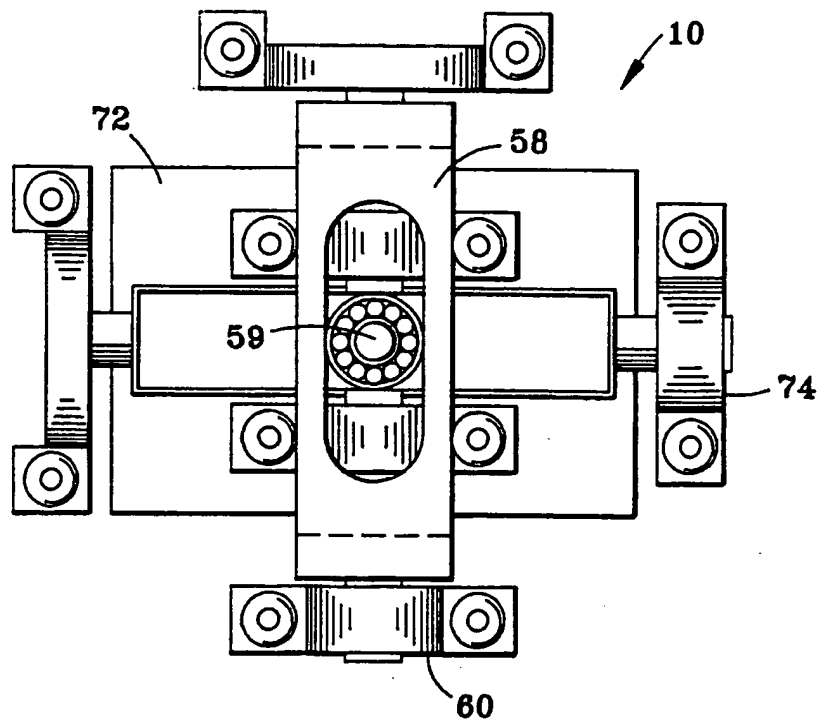


FIG. 8

5/6

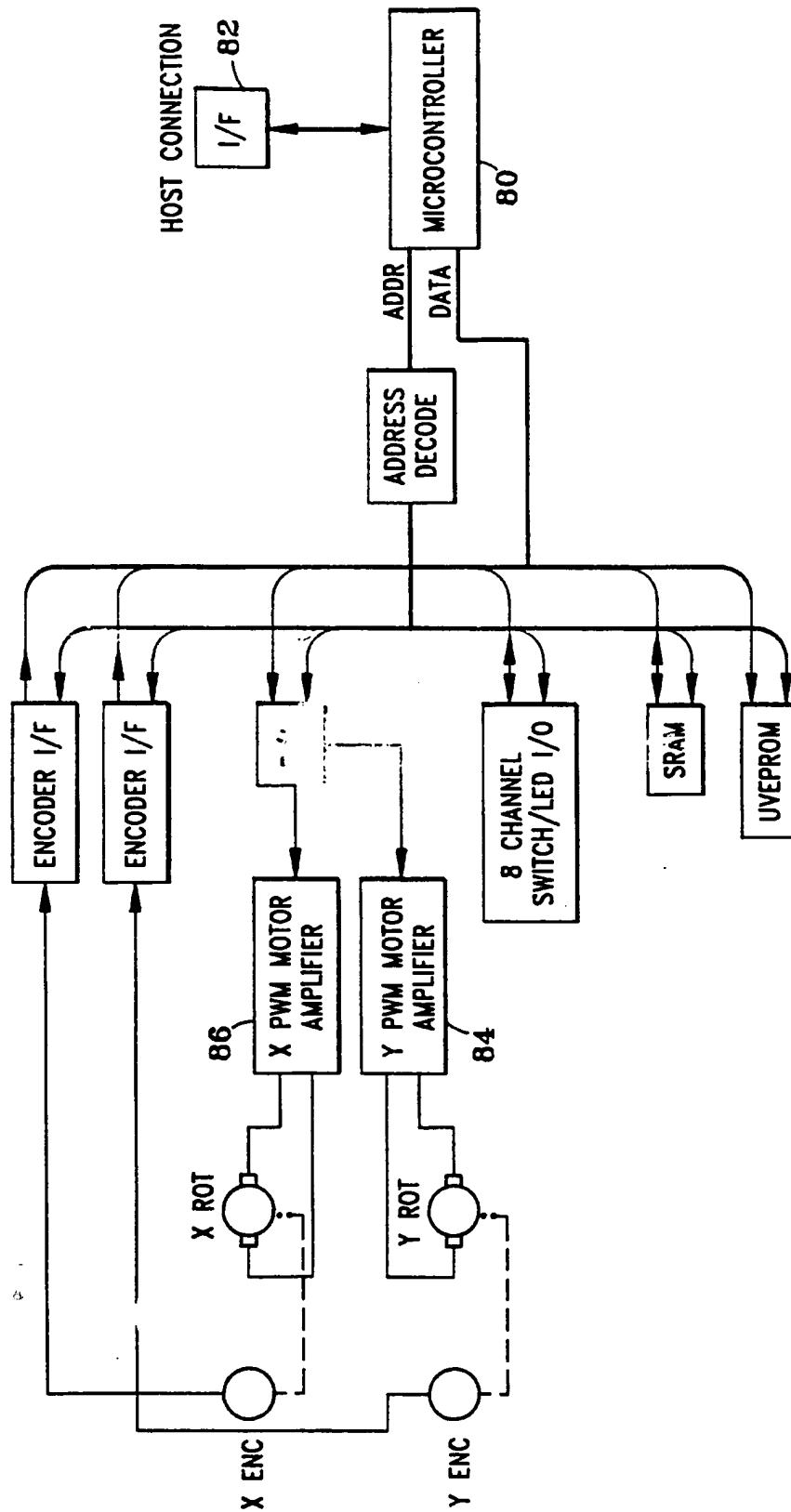


FIG. 9

6/6

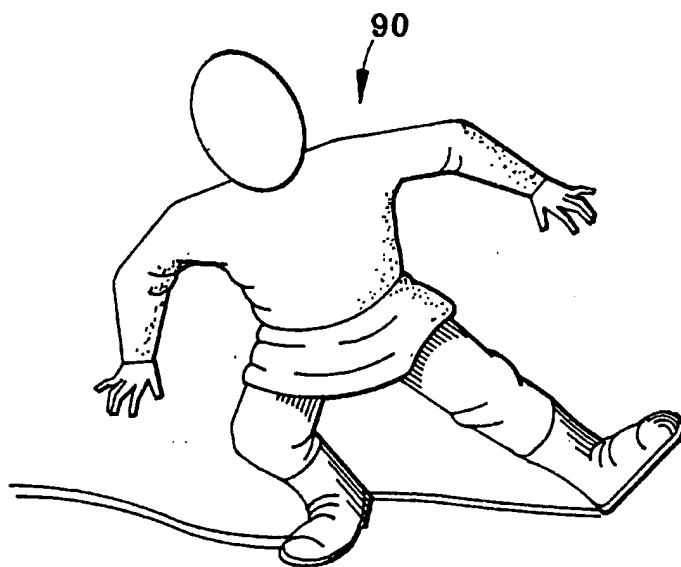


FIG. 10

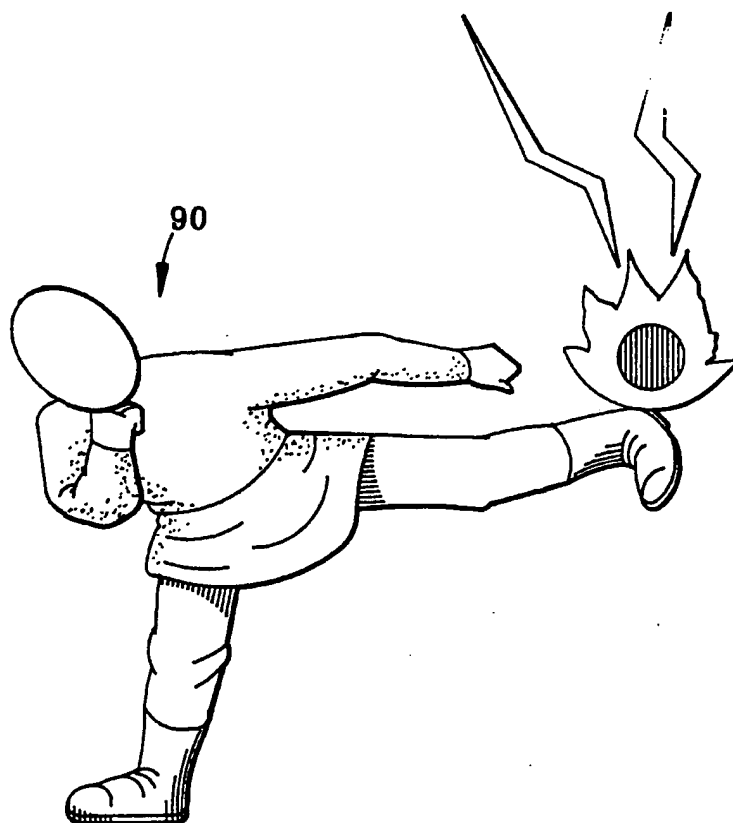


FIG. 11

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 95/06204

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 G06F3/00 G06K11/18 G09B9/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G06F G09B G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,3 919 691 (A. MICHAEL NOLL) 11 November 1975 see the whole document ---	1-9
X	EP,A,0 489 469 (ENGEL, FREDERICK LOUIS) 10 June 1992	1-3,8,9
Y	see the whole document ---	4-7
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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-3919691	11-11-75	NONE	
EP-A-0489469	10-06-92	NL-A- 9002669 JP-A- 4291414	01-07-92 15-10-92
FR-A-1102320	19-10-55	NONE	